# ATLAS PIXEL SYSTEM


## M. G. D. Gilchriese

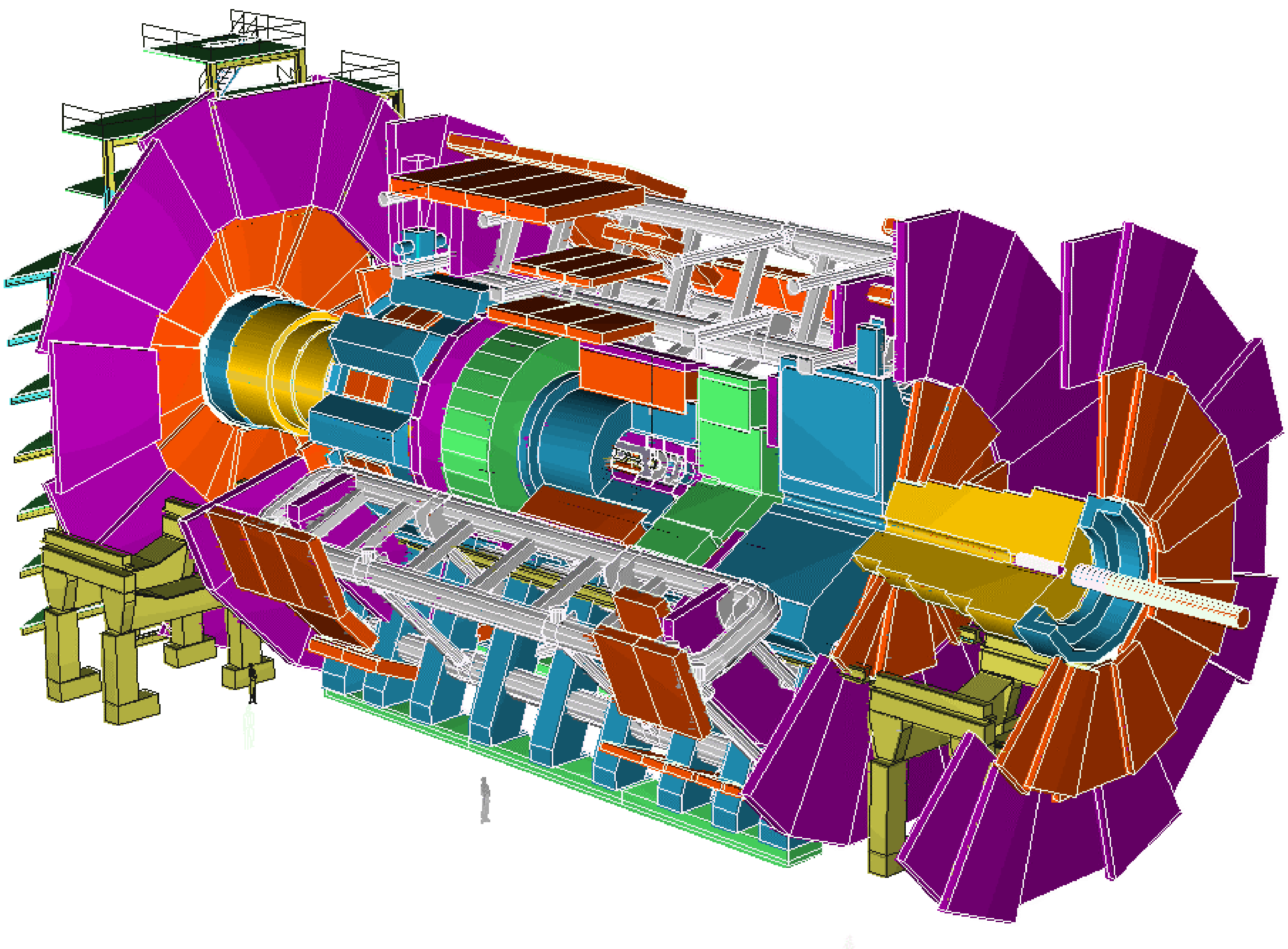
**Lawrence Berkeley National Laboratory**


Toronto
Mayl 1999

# Purpose

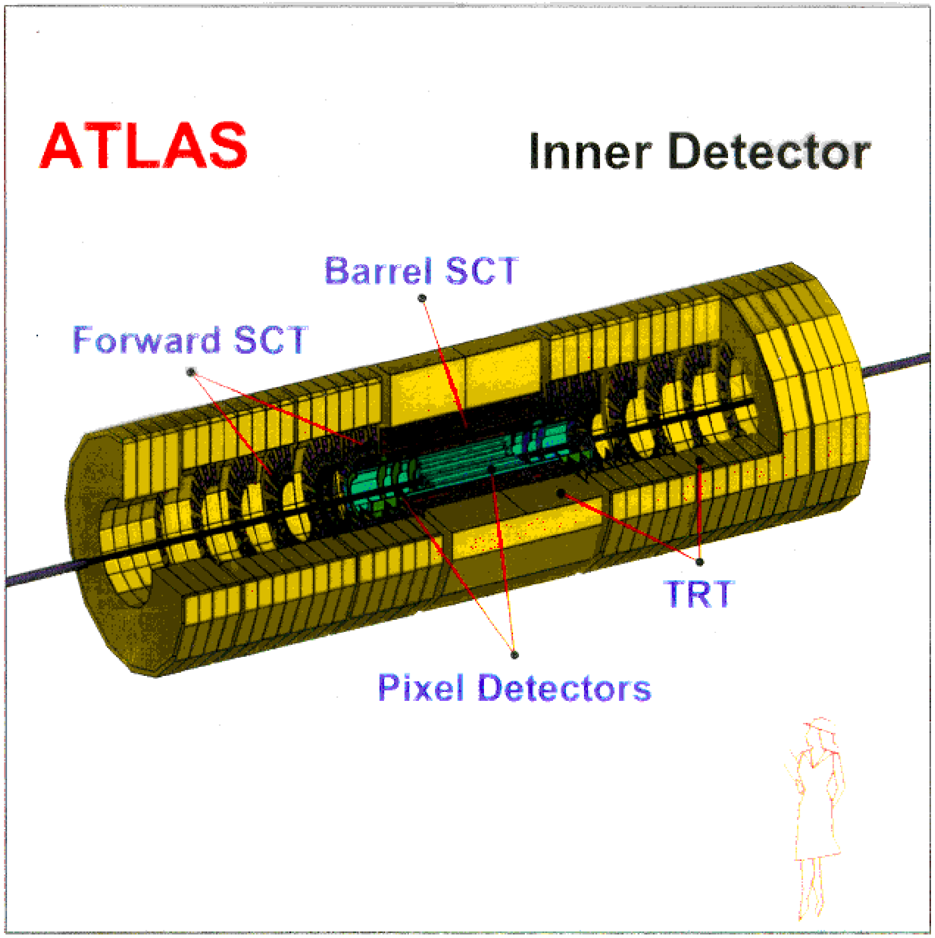
- Brief overview of status. Not a detailed technical talk.
- Who is doing what
- Areas needing more effort
- More background information
  http://www-atlas.lbl.gov/pixel/tdr.html
- and other links via ATLAS Web pages

# The ATLAS Detector



# ATLAS Inner Detector

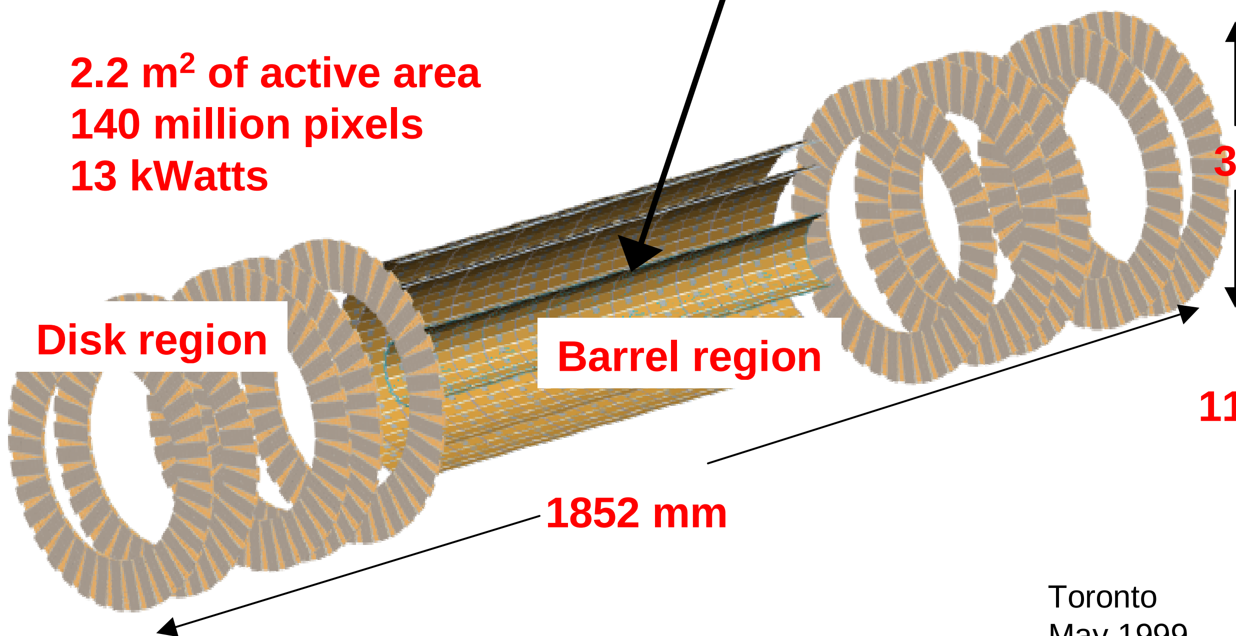
- **Inner Detector requirements**
  - Coverage $|\eta|<2.5$
  - $p_t$ resolution <30% at $p_t$ = 500 GeV
  - Efficiency >95%(isolated tracks) for $p_t$>5 GeV
  - e ID efficiency >90% for $p_t$ >5 GeV
  - b-tagging
  - z coordinate of primary vertex
  - Level 2 trigger
- **“Continuous” tracking with TRT**
  - Pattern recognition
  - Momentum resolution
  - e ID
- **Inner precision tracking with**
  - Semiconductor Tracker, now a silicon strip tracker
  - Pixels
  - Not a “vertex” detector only but a complete tracker
- **Ultimate performance from combined inner and outer tracking.**



# ATLAS Pixel System

- Layout
  - 3 barrel layers, 2 x 5 disk layers
  - Three space points for |η|< 2.5
  - Modular construction(2228 modules)
- Radiation hardness
  - Lifetime dose - 25 MRad at 10 cm
  - Leakage current in 50μx300μ pixel is - 30 nA after 25 MRad.
  - Signal loss in silicon by factor 4-5 after 25 MRad(or - $10^{15}$ n/cm$^2$)
- Pattern recognition
  - Space points. Occupany of - $10^{-4}$
- Performance
  - Critical for b tagging(big physics impact)
  - Need for 3 hits confirmed by simulation
- Trigger
  - Space points-> L2 trigger
- B-Layer
  - More demanding in almost all aspects
  - Evolving to essentially separate project

**2.2 m$^2$ of active area**
**140 million pixels**
**13 kWatts**

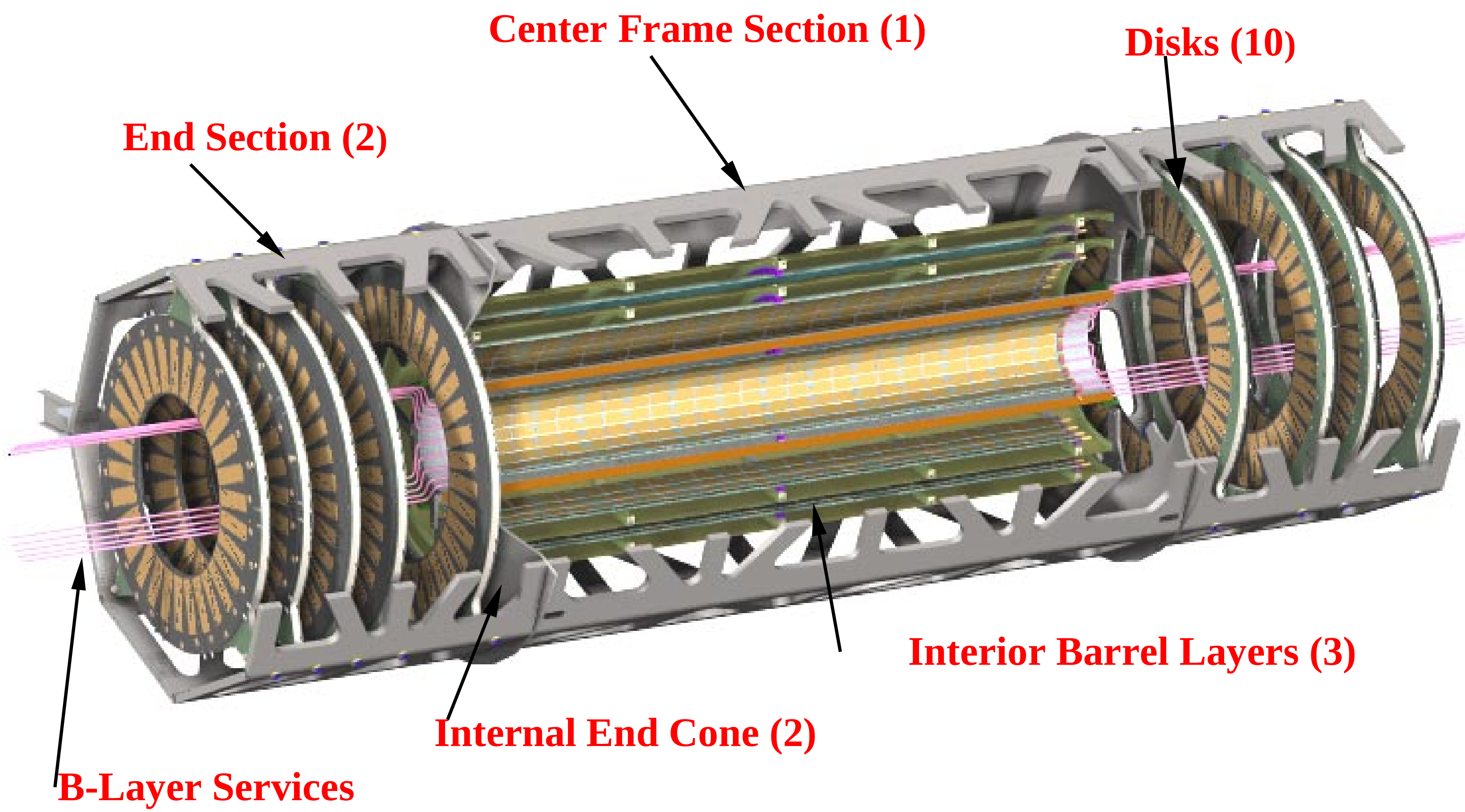



**2228 Modules**
**118 Barrel Staves**
**120 Sectors**

# General Status

- Canada, Czech, France, Germany, Italy,U.S. List is at
  http://atlasinfo.cern.ch/Atlas/GROUPS/INNER_DETECTOR/PIXELS/pixel.html#Institutes
- Relatively small group.
- Technical Design Report completed in May last year
- Approved by CERN committees and CERN to proceed
- Still very much in development phase.
- First final parts (detectors) would start early next year with other elements to follow
- Current critical path item is currently rad-hard IC electronics

# Pixel Mechanics

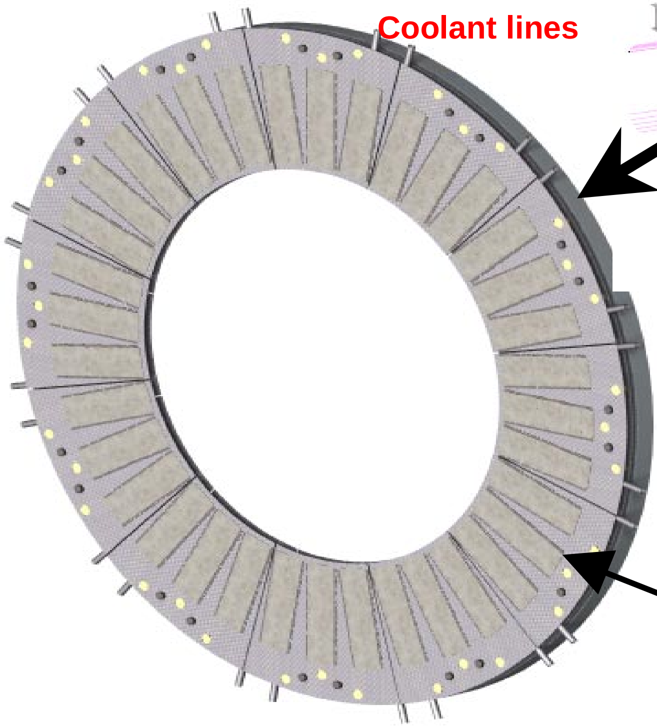


# Pixel Mechanics

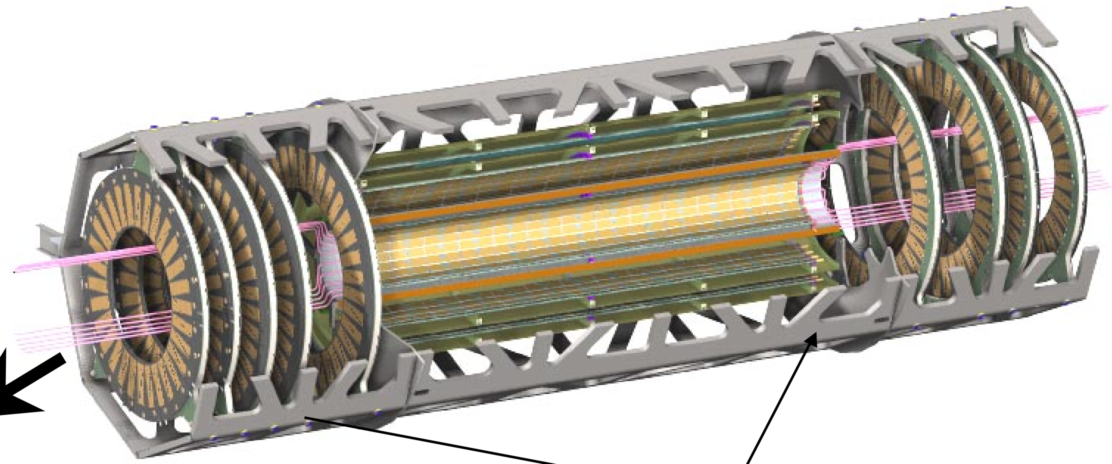
- **Local supports**
  - Locate modules, stable and integrated cooling
  - Staves in barrel region
  - Sectors in disk region
  - Both based on carbon-carbon for thermal management and support with integral cooling channel or tube
- **Global supports**
  - Composite structure: ultra-stable
- **Services**
  - Major effort on integrating power and cooling

# Pixel Mechanics - Disks

**Disk with 12 Sectors**



**Coolant lines**



**Support frame**

**Sector- local support of modules**

# Pixel Mechanics Status

- Many prototypes of local supports made and tested
- Evaporative cooling using fluorinert liquids chosen but details under review
- Conceptual design of global supports complete and prototypes of end sections and barrel shells underway
- Integration framework for services and installation established.

# Pixel Mechanics - Who Is Doing What

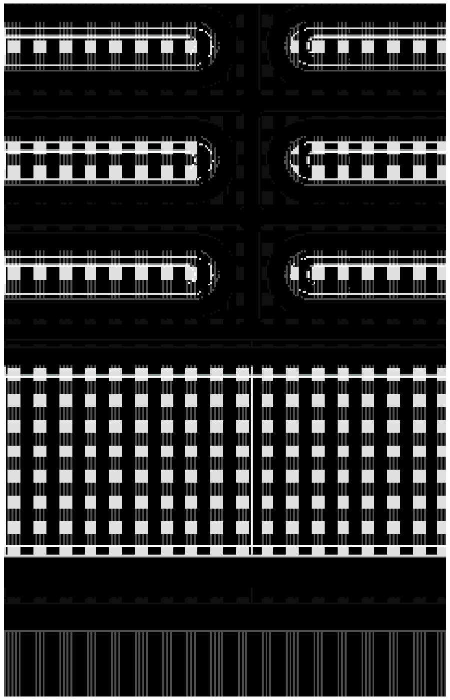
- LBL
  - Deliver disk region.
  - Outer frame and cones
  - Part of integration(services)
- Genoa(other Italy later)
  - Lead on local barrel supports
  - Contributing funds to frame prototype
- Marseille
  - Also work on barrel local supports
- Bonn/Wuppertal
  - Barrel global supports
- Everybody to work on final assembly at CERN, details to be worked out
- Rotating lead engineer based at CERN. Has been U.S. and Italy just starting. Integration.
- What’s missing?
  - X-ray alignment during final assembly at CERN

# Pixel Sensors

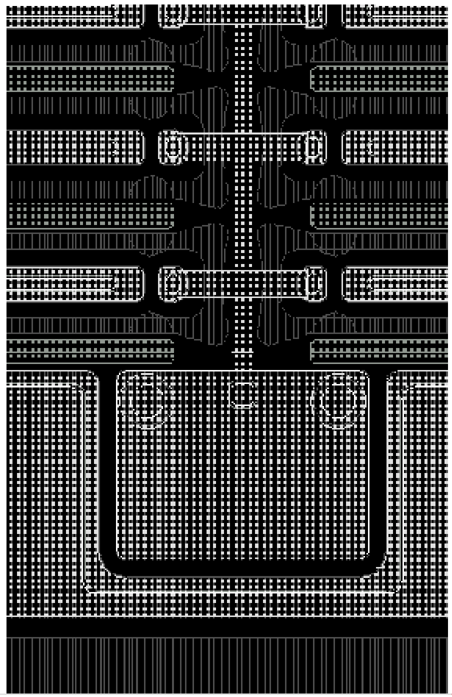
- Prototype 1.0 sensors fabricated(two vendors) and tested very successfully last year
    - Baseline design selected
    - This design has feature that allows testing(by punch-through biasing of the pixels)
    - Test beam results indicated improvement needed in implant design of baseline choice
- This improvement was implemented with minimal mask changes in prototype 1.5 round.
    - These wafers are just now available and irradiation and testing program has started.
    - Test beam starting in a few days
- Design of prototype 2.0 wafers is essentially complete
    - Will look like production wafers, but explore processing variations, including oxygen-enriched to enhance radiation hardness
    - Fabrication should start in few weeks with at least 2 vendors

# Sensor Designs

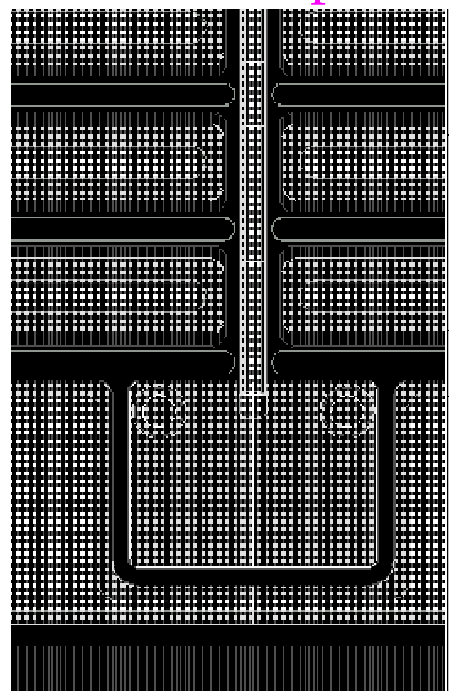
Tile 1



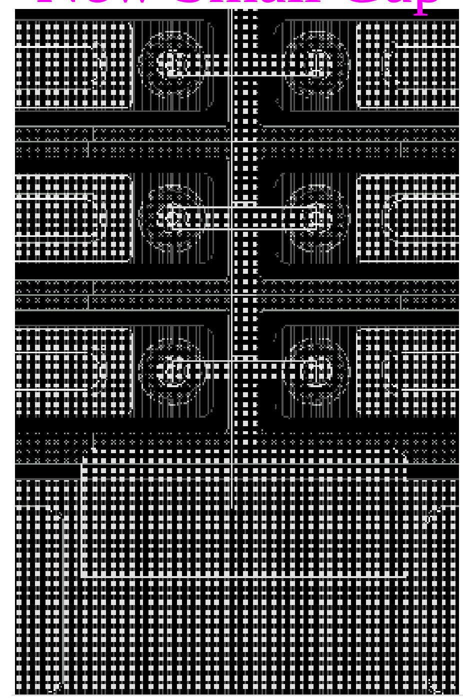
Tile 2



Small Gap



New Small Gap



p-stop

p-spray

1st prototype run

Revised 1st prototype run

# Sensors - Who is Doing What

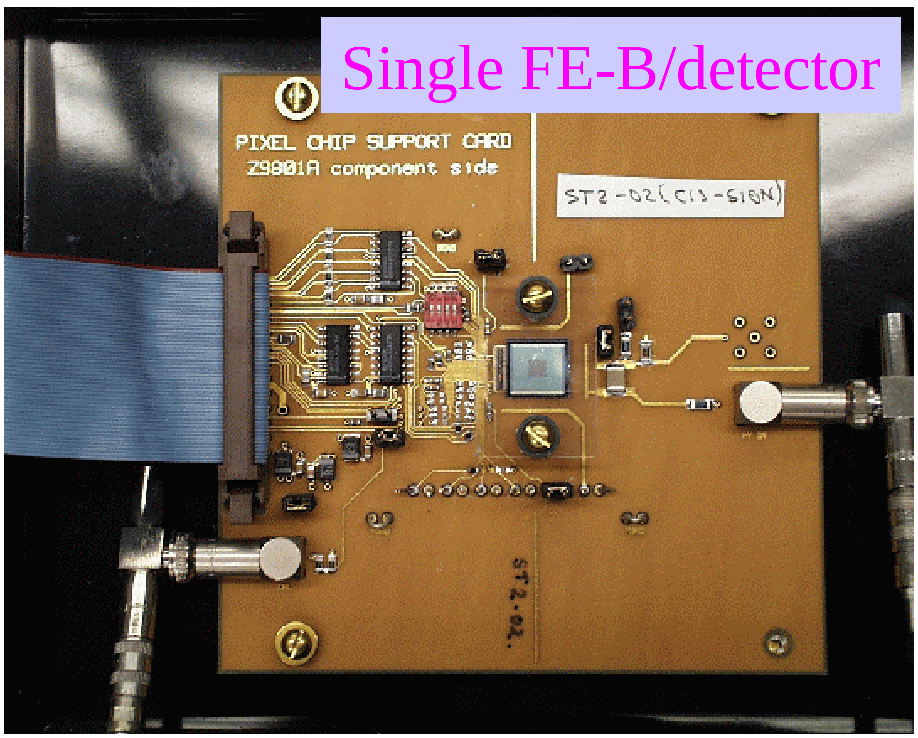
- Primary design activity is in Germany at MPI and Dortmund.
- Testing occurs at these institutes + Prague, Udine in Italy, New Mexico in U.S. Other U.S. institutions possible if needed.
- What's missing? Nothing at the moment, but B-layer demands different - see later

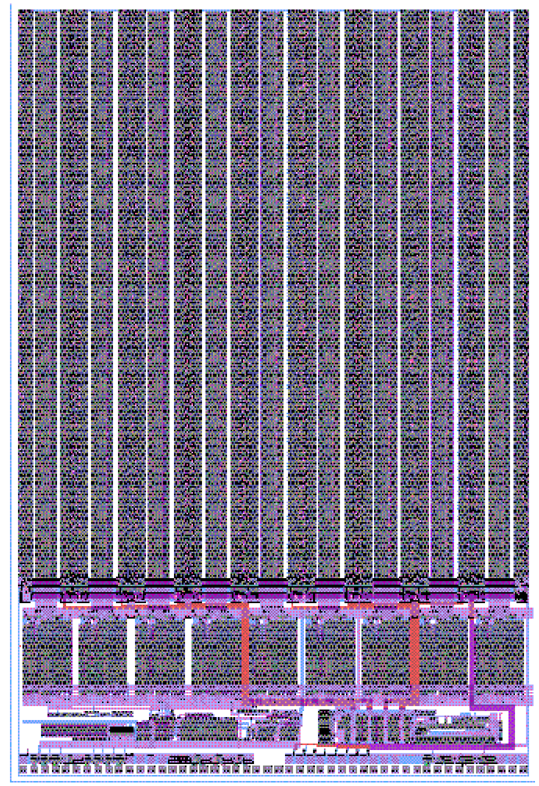
# Pixel Electronics

- Pre-prototype program completed successfully by end 1997.
- Full-scale prototypes fabricated in rad-soft technologies in 1998 and tested extensively. Different design approaches. FE-A, FE-B, FE-C.
- FE-A(AMS -> Temic/DMILL). First delivery in February. Functional. Yield about 5%. Second run delivered in July(all CMOS version FE-C). Yield appears higher, about 80%.
- FE-B(HP -> Honeywell SoI). First delivery in April. Functional. Yield about 93%.
- Unified design approach adopted for rad-hard design FE chips => all working on same design to be implemented in the two rad-hard processes
- Largely serial effort on rad-hard design(manpower limited). DMILL prototype first(FE-D) aimed at submission next month. Then Honeywell SoI(FE-H) later this year.

# Pixel Electronics

- FE-A/C and FE-B bonded to prototype detectors, including irradiated detectors.
  - 18x160 pixels(50x400 micron pixel size). Complete analog and digital to ATLAS specs. Spec is 50x300 micron pixel but 400 vs 300 micron performance comparison underway. Preliminary conclusion is 400 micron OK except for B-layer.
  - Essential requirements met(efficiency, time resolution, noise, threshold,….)
  - Multiple test beam runs at CERN. Extensive lab tests. Principle established.



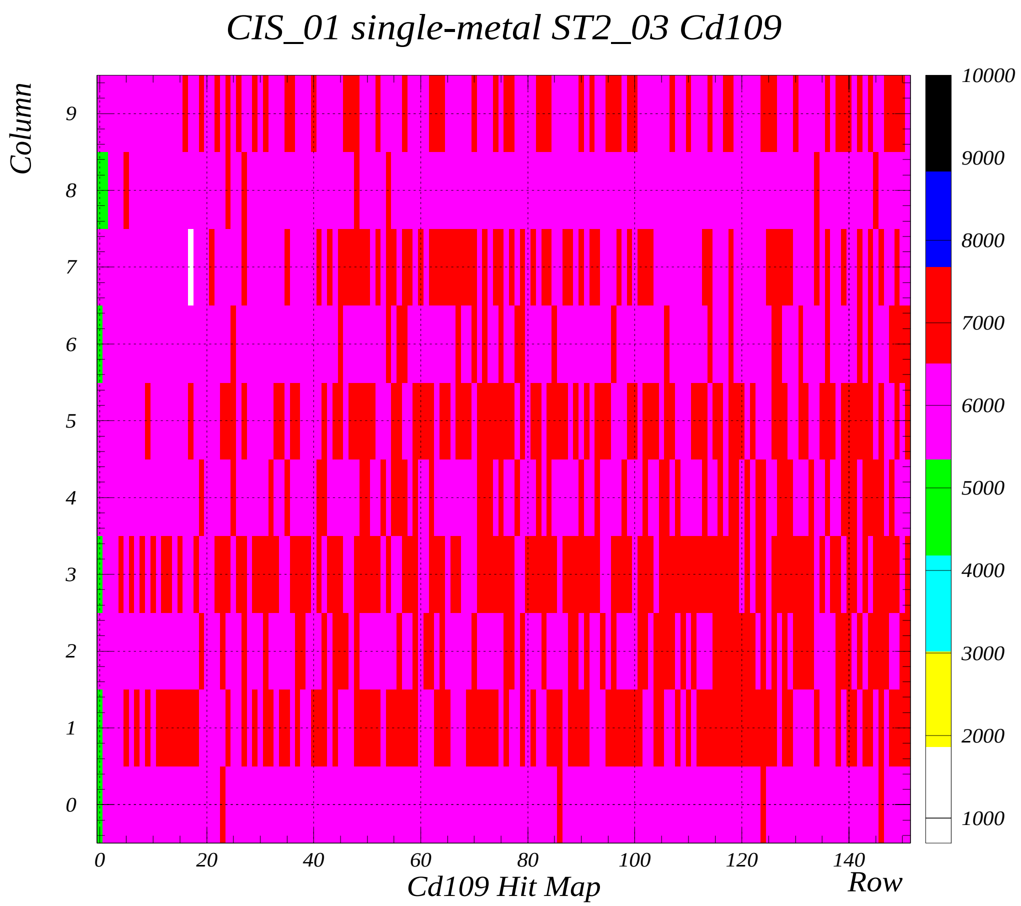



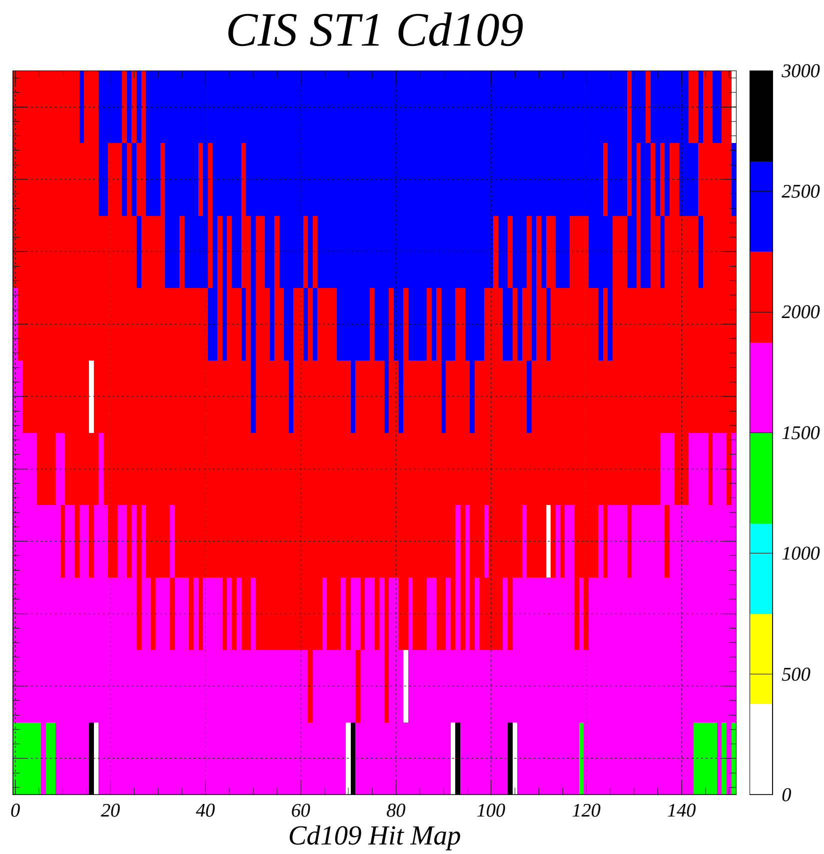
FE-B

# Lab and Test Beam Results - Summary

- Extensive lab tests and three test beam runs in 1998. Very successful.
- Highlights
  - Dozens of single-chip/detectors have been operated successfully with multiple detector types and front-end ICs
  - 16 chip modules have been operated successfully
  - Detectors irradiated to lifetime fluence expected at LHC($10^{15}$) have been read-out in a test beam with efficiency near 100%
  - Operation below full depletion voltage demonstrated
  - Preferred detector type identified in these studies
  - Timing performance needed to identify bunch crossings has been demonstrated, albeit not at full system level.
  - Operation at thresholds 2,000-3,000 electrons demonstrated
  - Threshold uniformity demonstrated.
  - Spatial resolution as expected
- Conclusion
  - Proof-of-principle of pixel concept successful

# Photon Source Test of FE-B and Detectors

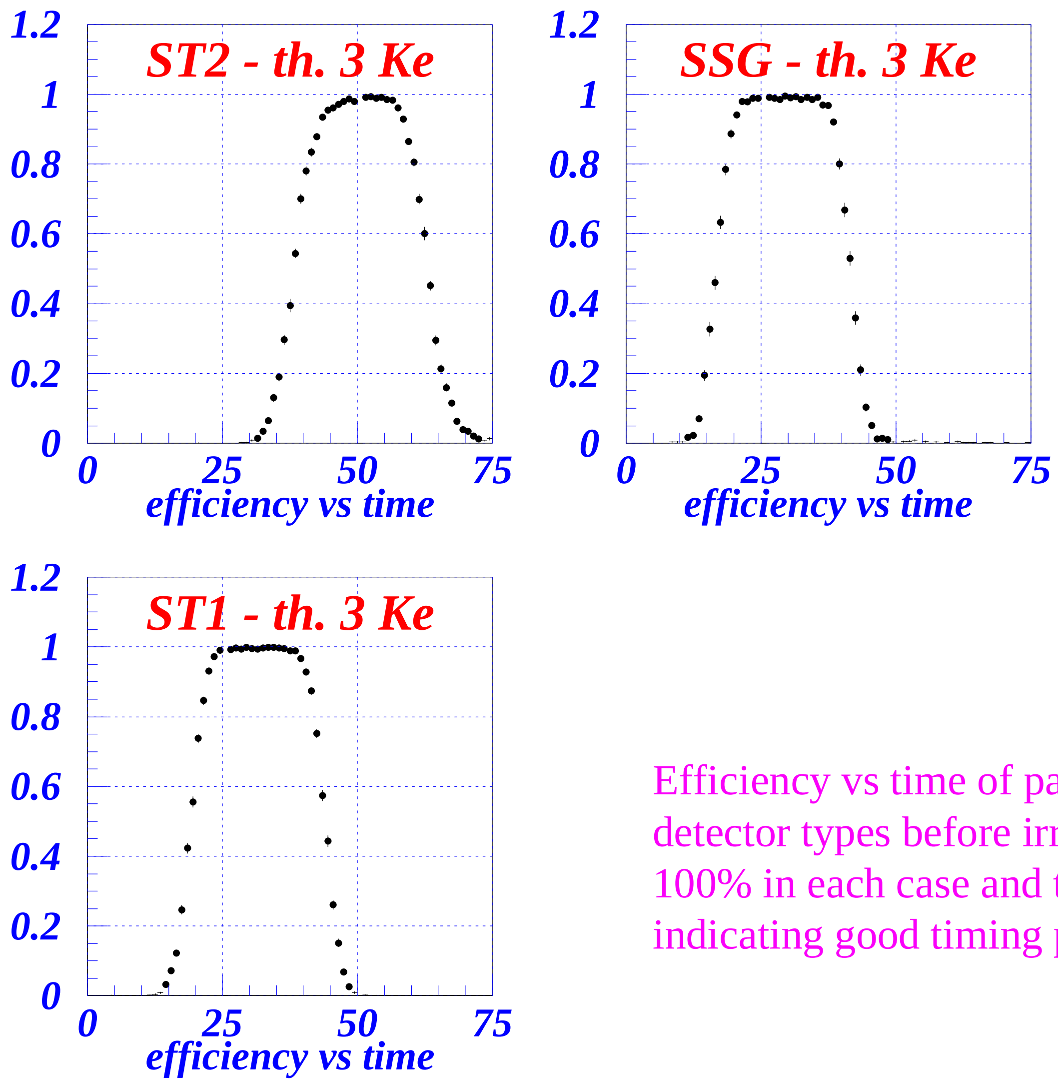




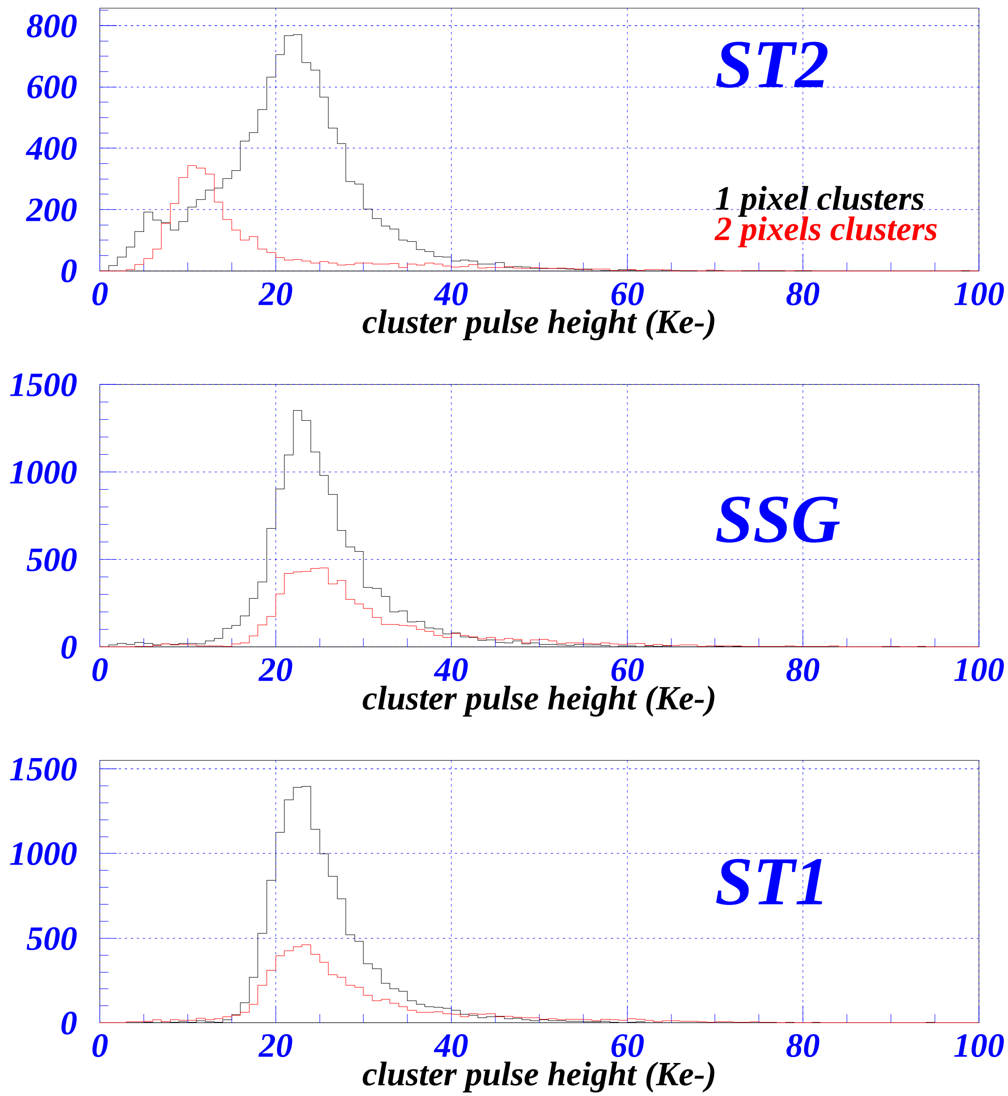

Toronto
May 1999

# Lab and Test Beam Results - Examples




Efficiency vs time of particle passage for three different detector types before irradiation. The efficiency is near 100% in each case and there is a substantial plateau, indicating good timing performance of the electronics

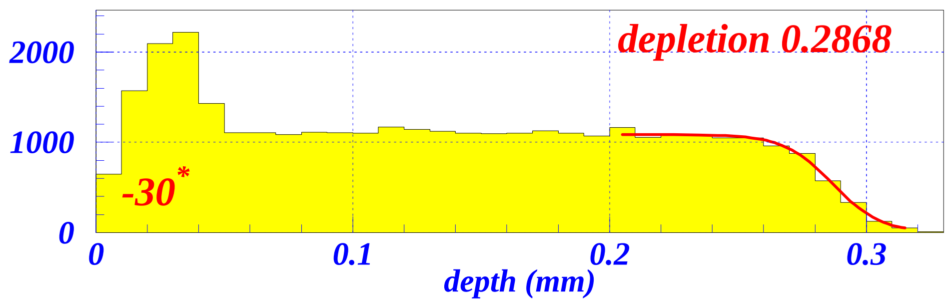
# Lab and Test Beam Results - Examples

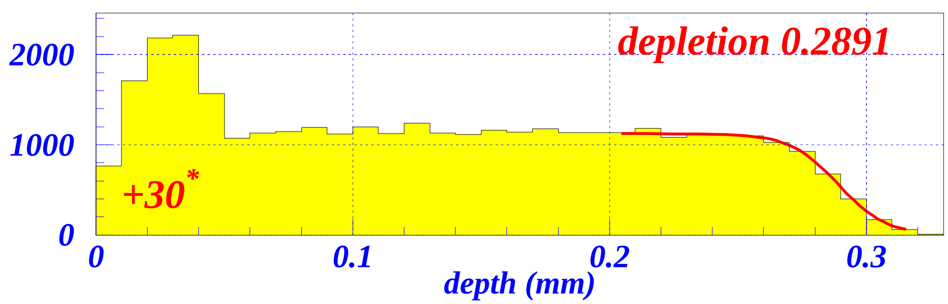


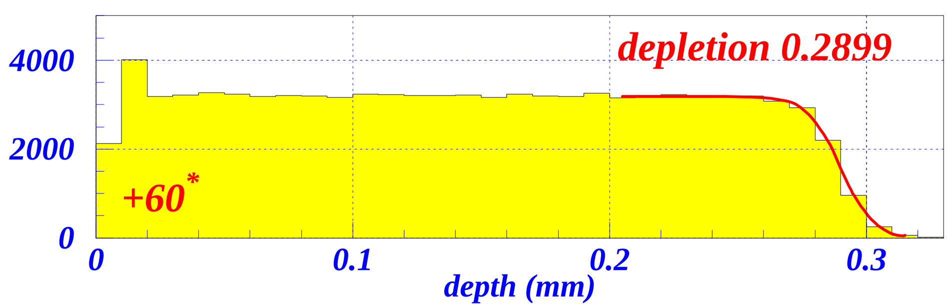

**Charge distributions for three detector types. The difference between ST2 and the others is indicative of small charge losses, which has guided us in the design of additional prototype detectors under fabrication.**

# Lab and Test Beam Results - Examples

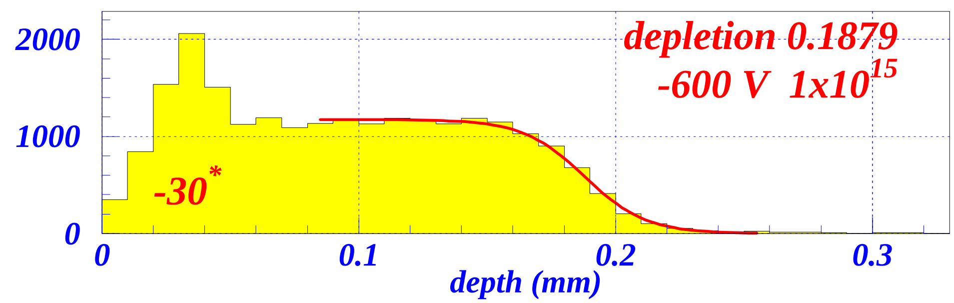
Not irradiated - depletion depth

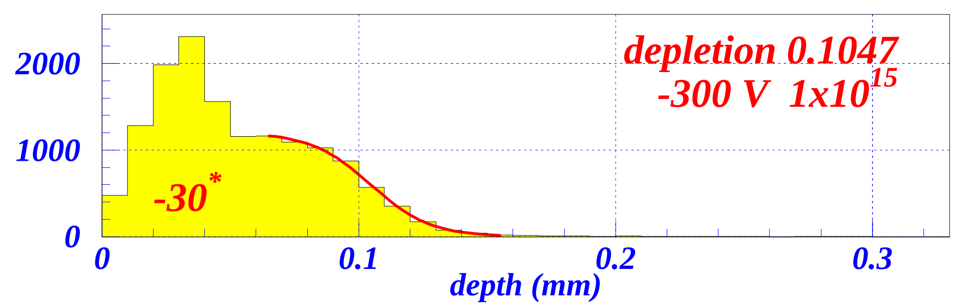


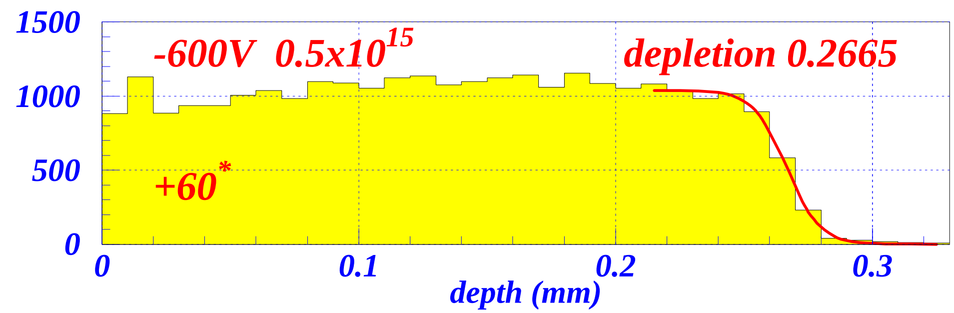



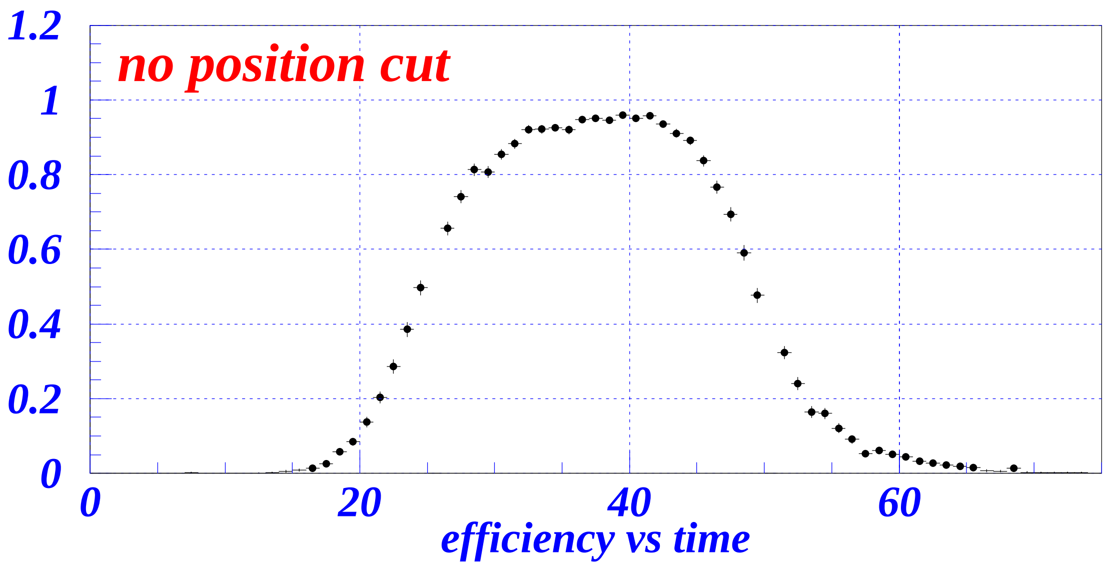

Irradiated - depletion depth

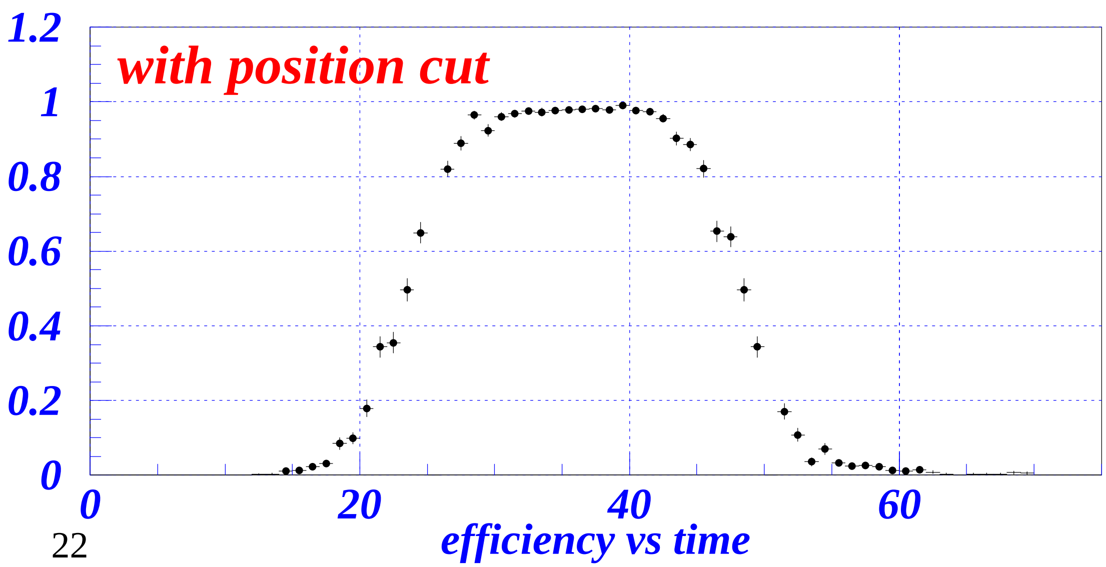


# Lab and Test Beam Results - Examples




Efficiency after irradiation of $1x10^{15}$ without and with a position cut to remove tracks near the edge of the pixel.

# Electronics - Who Is Doing What

- Rad-hard electronics design well underway. Hope to submit first full-scale prototype to Temic next month
- Front-end IC collaboration among LBL, Bonn and Marseille
- Module Clock and Control Chip mostly Genoa with bit of help from LBL and Bonn
- Optical drivers/receivers(adapted from SCT) by OSU and Siegen so far.
- What's missing. IC engineering in short supply. User testing also. Requires major commitment to get involved.

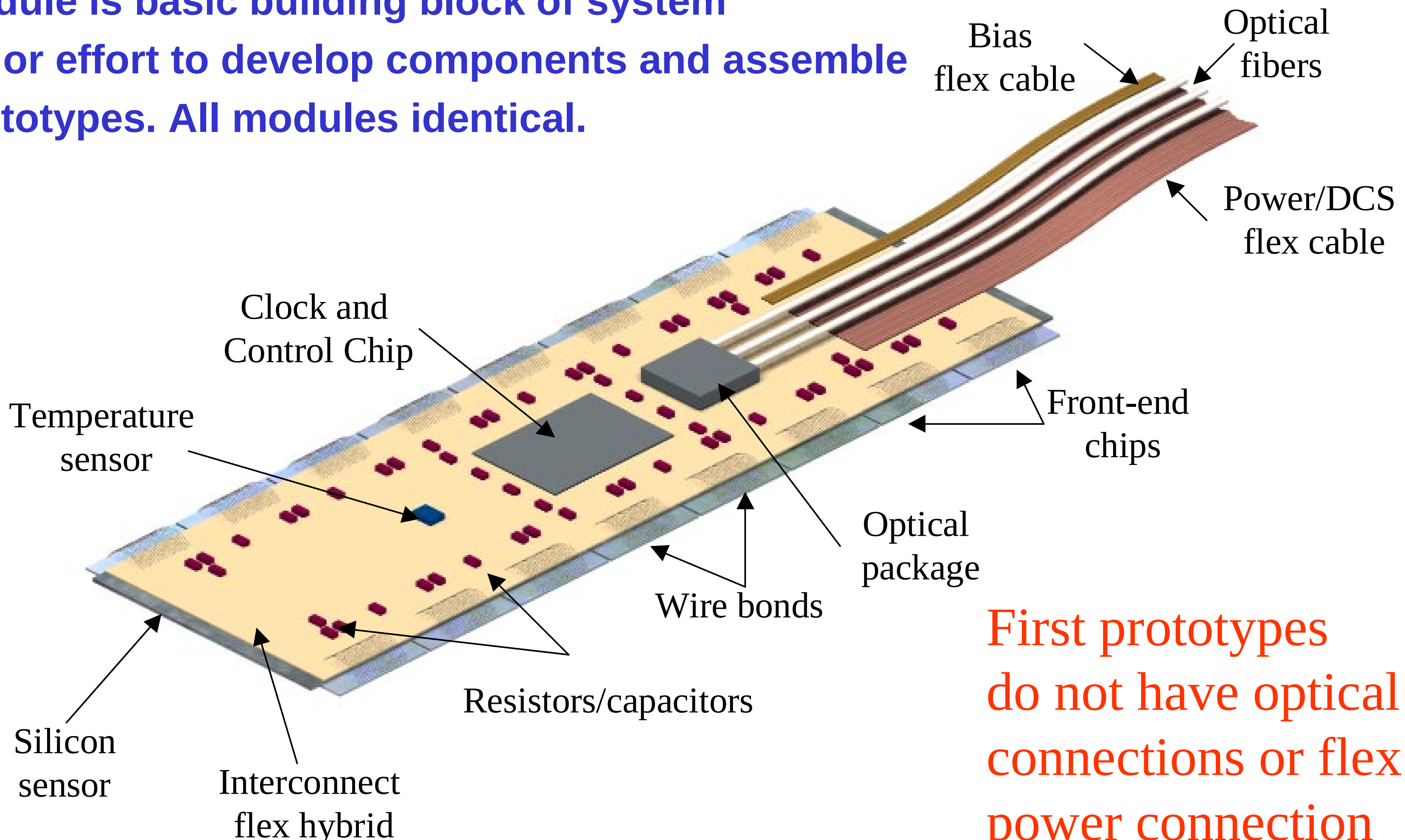
# Off-Detector Electronics

- Read-Out Drivers connected to pixel detector by fiber optics.
- In early design phase by Wisconsin, Irvine and UK groups, since joint SCT/pixel effort
- Test and lab beam support being provided by custom VME boards.
- PC-based software system developed(LabWindows)
- Test systems in place in about 12 dozen institutes.

# Pixel Module

**Module is basic building block of system**

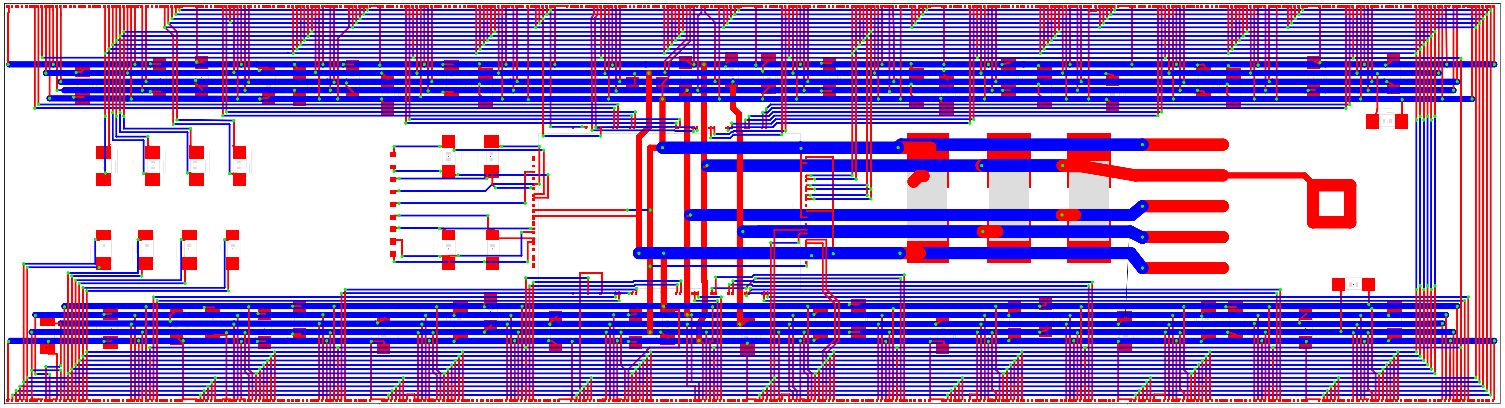
**Major effort to develop components and assemble prototypes. All modules identical.**




First prototypes do not have optical connections or flex power connection

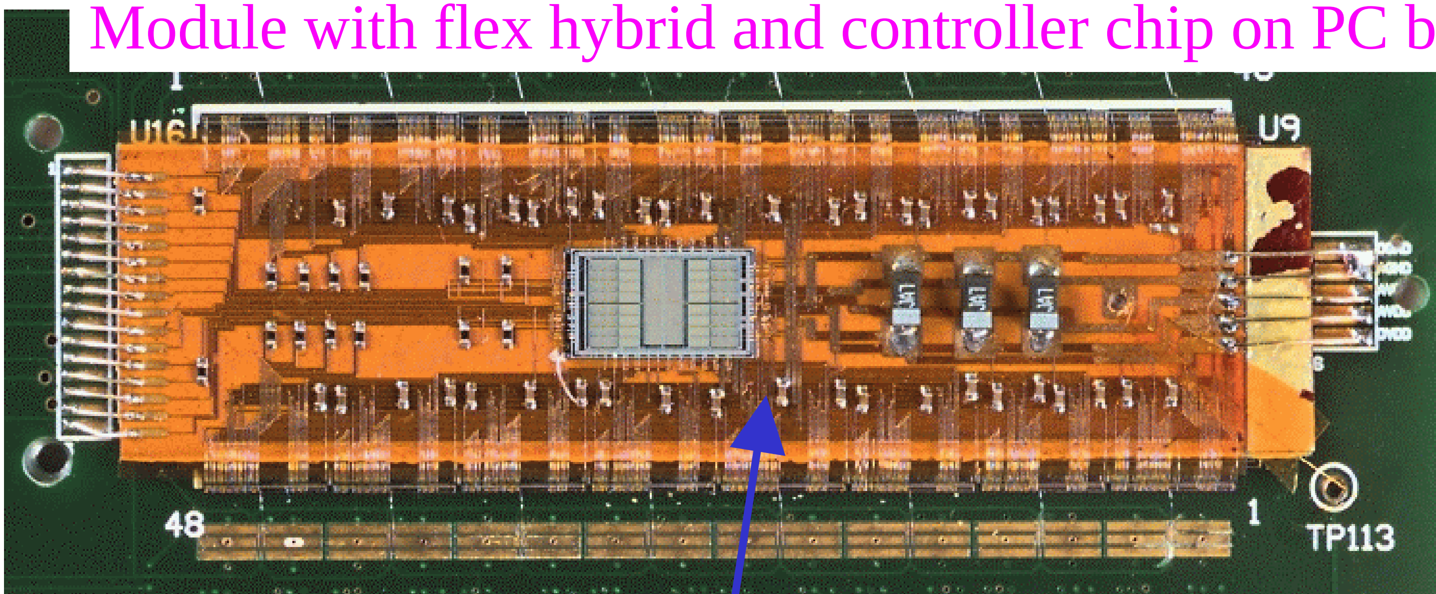
# Pixel Hybrids

- **Flex hybrid interconnect technology selected February 1999 as baseline for disks and two outer barrel layers. B-layer alternative technology(MCM-D) if it proves to be feasible, otherwise flex hybrid.**
- **Prototype flex hybrid(v1.0) designed at Oklahoma and fabricated successfully at CERN**
- **Few modules built and tested.**
- **Design of revised and improved version(1.x) complete except for vendor specific items. Fabrication planned with at least two vendors in next few months.**
- **Issues**
  - **Production yield and impact on module assembly => build many more**

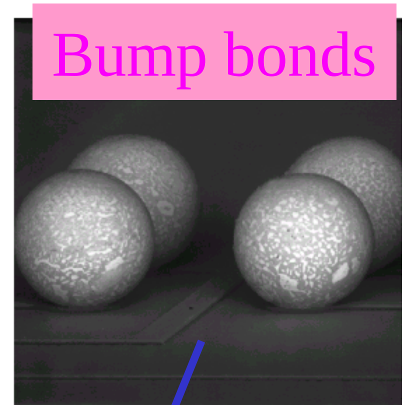


# Pixel Modules

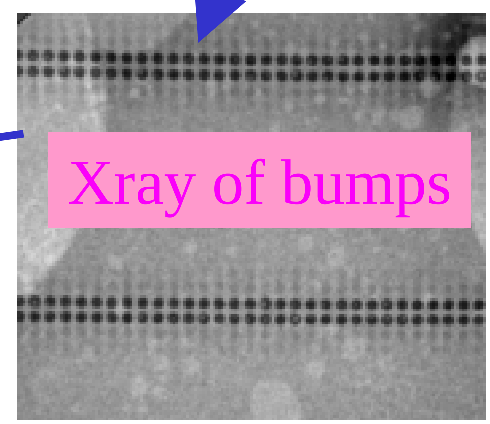
Module with flex hybrid and controller chip on PC board




Bump bonds



16 chips with 46,000 bump bonds



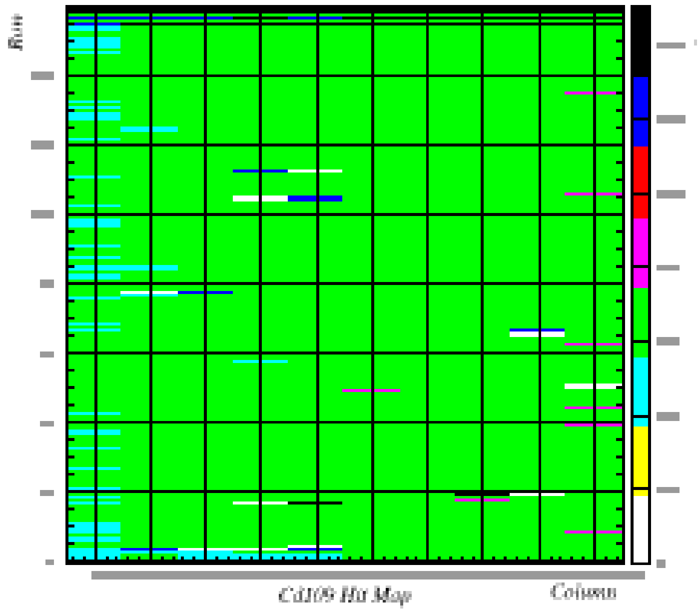
Xray of bumps

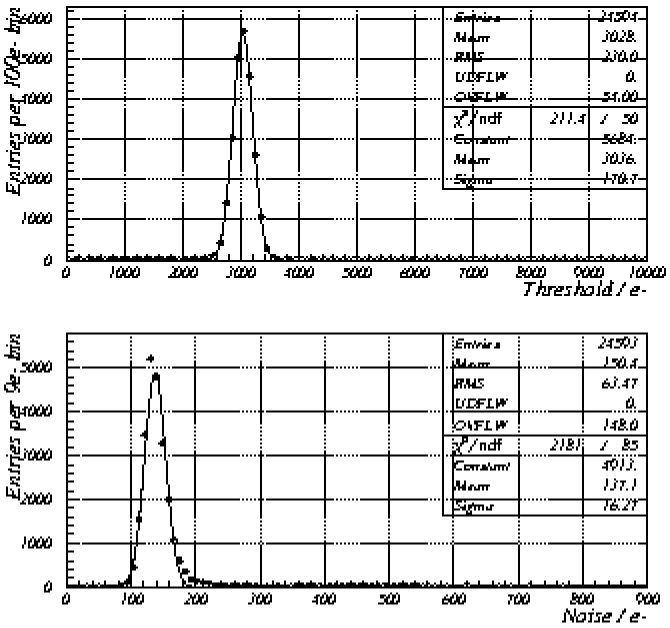
Sensor

ICs

# WBS 1.1.1.5 Pixel Modules

- Bump bonding under control for prototypes but much more work needed on production issues.
- A handful of modules(including bare modules) built and tested
- So far has been largely test bed for electronics and concept(can you operate 16 chips on a sensor? Yes)
- Issue - production aspects => contracts in place to build 100 module over next year.



# Modules - Who Is Doing What

- **Bump bonding is now mostly in Europe, with Bonn and Genoa as the contacts.**
- **Module assembly will be done at many sites but really not serious yet.**
- **Module testing potentially even more**
- **Optical components: borrowing from SCT development but OSU is prototyping different package(to be cheaper)**
- **With the exception of bump bonding, all of these areas are currently weak.**

# Services and Related

- Cabling and piping has so far been part of overall integration.
- Prototype cable plant from module to power supplies by LBL this year. Long term not understood.
- Power supplies so far by Wuppertal but needs help.
- These areas are also weak at the moment.

# B-Layer

- More demanding than other parts of system
  - Higher rates => higher occupancy=> slightly different electronics
  - Higher radiation levels(would like 100 Mrad capability) => different sensors? Diamond? Oxygen-enriched silicon? Long shots are cryogenic silicon and silicon carbide.
  - Smaller pixel size to avoid confusion => different electronics and higher power
  - Must be removable and replaceable => different mechanics (and very difficult)
- In short, evolving into separate and later project.

# Conclusion

- Group currently too small to meet all needs on desired schedule.
- Particular areas needing more effort
  - IC engineering(but some help on the way)
  - System tests ie. Modules, single-chip assemblies but requires full-time effort to keep pace
  - X-ray alignment. Nobody working.
  - Power supplies.
  - Power cabling.
  - Perhaps optical components(too soon to tell)
  - Module assembly/testing